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Dynamic simulation of government subsidy policy effects on solar water heaters installation in Taiwan

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ABSTRACT

Because of the increasing shortage of international energy sources and greater climate change related to global warming, developing renewable energy sources has been emphasized by numerous countries. Solar energy provides a type of clean and non-polluting renewable energy source and contributes greatly to relieving the energy and environment crises. In response to the international increase in energy prices, and under environmental pressure to reduce global emissions of greenhouse gasses, promoting solar water heaters (SWHs) has become a crucial aspect of the Taiwanese government's energy saving policies. This study used system dynamics to explore the causal relationship of solar water heater installation in Taiwan and simulated relevant government policies. The results showed that if the government in Taiwan continues to subsidize SWH installation with NT\$2250/m^2, SWH installation areas will reach the promoted target of 1,40,000 m^2 by 2020.

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1. Introduction

Saving energy and reducing carbon emissions are the core of government policies in Taiwan. In response to the international increase in energy prices, and environmental pressures to reduce global greenhouse gas emissions, promoting solar water heaters (SWHs) has become a significant aspect of the Taiwanese government's energy saving policies [1]. However, can the annual SWH installation area target be reached by 2020 if the government continues to provide the current NT$2250/m^2 in SWH installation subsidies? How do increases or decreases in government subsidies and raw material prices influence the SWH installation area? Government authorities and SWH business managers all want the answers to these questions.

In recent years, countries worldwide have focused on climate change and global warming. An increasing shortage of international energy sources, greater climate change caused by global warming, and rising energy prices has motivated numerous countries to emphasize the development of renewable energy sources. Fairey [2] highlighted that the world has between 30 and 60 years of oil remaining. Roaf et al. [3] believed that stocks of natural gas could last for a further 65 years at the current rate of consumption. Sovacool and Watts [4] suggested that at the current rate of consumption, the world has less than 200 years of fossil fuel supplies, 65 years of natural gas, 70 years of uranium, and 164 years of coal remaining. Roulleau and Lloyd [5] stated that anthropogenic global warming and resource depletion has led many countries to attempt to reduce their fossil fuel use and CO_2 emissions by switching to renewable energy sources.

Taiwan is an island country lacking traditional energy sources. Statistics show that more than 96% of the energy used in Taiwan is imported from foreign countries [6]. With Taiwan's flourishing economic development, the need for energy has consistently increased, leading to greater dependence on imported energy sources, which significantly influence socioeconomic developments. Renewable energy sources should be the focus of independent energy resource developments in Taiwan; its development will also provide long-term benefits to environmental protection. Renewable energy sources refer to energy sources where a constant provision is guaranteed. The renewable energy sources currently used by humans include solar energy, wind power, geothermal energy, water power, tidal energy, marine thermal energy, and biomass. Among these energy sources, solar energy refers to the radiant energy received by the earth from the sun, which directly or indirectly provides most of the energy on the earth.

Solar energy is an inexhaustible resource and SWH business is a part of the solar energy industry. Transforming sunlight into thermal energy using SWHs can reduce carbon emissions to the standard agreed in the Kyoto Protocol. The Bureau of Energy [6] stated in its report that every square meter of an SWH collector area can save 68 l of oil each year, and every square meter of an SWH collector area can reduce 190 kg of CO_2 emissions. Baumert et al. [7] highlighted that each home could save 5000 t of CO_2 per year through the elimination of liquefied petroleum gas leaks and the installation of SWHs. Islam et al. [8] highlighted that SWHs can make a significant contribution to CO_2 emission reduction as each installation reduces conventional energy use by 40–50%. SWHs industry is a significant green industry enabling the sustainable human development.

An SWH is a device that heats water using the solar energy collected by a solar thermal collector. SWHs are a commodified product with significant economic value and the most mature technology of all solar thermal energy applications. Taiwan is located at 120°–121° east longitude and 22°–25.5° north latitude, with an average annual temperature of 22 °C. The northern and central areas receive an annual average of approximately 1500 h of sunlight, and the south receives 2000–2500 h. The average radiant heat intensity is 716–1027 kcal/day m^2 [9]. Therefore, Taiwan is a very suitable location for developing SWHs.

Chang et al. [10] highlighted that the factors influencing the installation of SWHs in Taiwan include the sunshine duration and solar intensity, cost of SWHs, energy prices, typhoons, and the type of buildings. Almost all SWHs were installed on the flat roof of building. An average of three to four typhoons each year affects Taiwan. When a typhoon passed over Taiwan, numerous damaged SWHs were reported. The potential number of households using SWHs also depends on the availability of space for installation. Over 60% housing in Taiwan is cottage or duplex houses, which are more likely to install SWHs on the roof. Han et al. [11] emphasized that solar energy utilization is highly dependent on the climate conditions at specific sites and the most important climate factors are the sunshine hour and sunshine radiation. Liu and Wang [12] believed that with the rapid increase in the energy prices, SWH has better competition and is more popular compared with conventional gas combustion and electric-driven water heaters. Taiwan has a subtropical climate with an average daily insolation of 3000–4300 kcal/m^2. Compared with other regions in the world, Taiwan has a high exposure to solar energy, rendering it extremely suitable for applications of SWHs [13]. Xia et al. [14] stated that solar energy systems have the advantages of reliability and safety without any environmental pollution as compared with conventional energy.

Roulleau and Lloyd [5] reported emphasized that government policy types to increase the uptake of solar water heating include collector-area-based subsidies, performance-based subsidies, tax credits, tax deductions, and mandatory policies. The countries that have adopted collector-area-based subsidy policies include Germany, Austria, the Netherlands, and Taiwan. The countries that have adopted performance-based subsidy policies are Sweden and Netherlands. France has adopted the tax credit policy, and Greece has adopted the tax deduction policy. Spain and Israel have adopted mandatory policies. The Taiwanese government's policy support tools for the SWH industry include system cost subsidies, research and development sponsorship, and production equipment tax remittance [15].

The European Solar Thermal Industry Federation (ESTIF) [16] has reported that financial incentive schemes (FIS) in the form of direct grants have played an important role in the development of the leading solar thermal markets in Europe (Germany, Austria, and Greece). In the fastest growing solar thermal market (France), income tax reductions have significantly accelerated the market growth since 2005. Chang et al. [10] reported that the Taiwanese government initiated a 6-year incentive program (1986–1991) to increase the installation of SWHs. Subsidies were granted for purchasing SWHs. Consequently, the installation area of solar collectors reached approximately 60,000 m^2/year in Taiwan.

Numerous factors influence the installation of SWHs, such as government policies; safety, climate, and economic factors; and

business operation strategies [5,10–12,15–17]. However, the installation of SWHs is primarily driven by government policies, which have a crucial influence [5,10,15,18–20]. Extant studies have mainly focused on policy implementation for ex-post impact assessments; however, forecasting the preceding effects and ex-ante predictions to achieve carbon reduction targets are important research topics. Thus, from a holistic perspective, exploring SWH installation factors will increase academic understanding of SWH installation behaviors for assessing policy effectiveness, which will assist the government in formulating a promotion policy.

The quantitative methods most often used for assessing policy effectiveness include econometric models, and cost–benefit analysis. Econometric models require sufficiently long-term data. Cost–benefit analysis requires the identification of the costs and benefits of actual policy. However, good quality data are frequently difficult to retrieve [21]. The methods described above emphasize the direct relation between parameters and effectiveness. This study is more concerned with the whole picture of the process of shift that is affected by policies.

In practice, the installation of an SWH depends on numerous factors, which have a series of interactions. For example, if SWH installations reached a certain economic scale, the cost of individual installations would decline. This decline in installation costs would increase installation incentives, further increasing SWH installations. Thus, the increase in SWH installations forms an economy of scale. This study targeted the installation problems faced by the SWH industry in Taiwan, examining the effectiveness of government policy. It is significant to reveal how these factors and policies work among this system.

For addressing the issues examined in this study, system dynamics developed by Forrester is the optimum approach. System dynamics can be used for analyzing and simulating a complex feedback system in policy analysis over time. The real influences of a social system on policies can be observed and understood in the system [22]. Homer and Hirsch [23] highlighted that system dynamics can identify multiple interactions among populations, diseases, risks, epidemiology, and health-related delivery systems. They added that system dynamics can be used to identify feedback loops and alter the perspectives of health policies. Naill [24] suggested that U.S. energy policies adopt a system dynamics approach to establish strategies to reduce dependence on foreign energy. In addition, system dynamics are effective for supporting business strategies. Companies can consider interactions among all business units using a system dynamics model, which enables management teams to achieve effective communication and consensus-building under dynamic situations [25]. Gupta et al. [26] built a system dynamics model to analyze the productivity of just-in-time systems. Bui and Loebbecke [27] developed a decision support system using a system dynamics model to forecast the supply and demand of the mobile phone market.

By employing a systematic thinking model and simulating the effects that government subsidy policies have on SWH installation, the results of this study can assist government authorities and SWH business managers in designing relevant managerial and operational strategies for future development directions.

2. Current conditions of the SWH industry in Taiwan

In the renewable energy industry, SWHs are the only application that Taiwan has the ability to produce entirely [15]. In Taiwan, SWHs are primarily used in households as water heaters, and the dominant system type is natural circulation systems, which account for more than 90% of the SWH market. Dormitories and hospitals typically adopt forced circulation systems. Most individuals select solar thermal systems for environmental protection and usage cost reasons.

A natural circulation system heats water by filling the circuits at the bottom of a solar collector with cold water. By absorbing solar thermal energy, cold water is transformed into heated water, which has a lower density. The heated water is then extracted, based on the siphon principle, into a hot water storage tank. Because the hot water storage tank must be mounted above the collector, a natural circulation system can only be installed on flat-roof buildings or open ground, which reduces the possibility of integrating this system in buildings. The primary difference between forced circulation systems and natural circulation systems is that forced systems pump cold water into the collector, enabling the hot water storage tank mounting to be determined based on the building type. Thus, the structure of a forced circulation system is more complex than that of a natural circulation system.

Most SWHs commonly used in Taiwan today follow a design from the 1960s, where the collector, water tank, and mounting bracket must be assembled and installed on the building roof [15]. While Although buildings in Taiwan are primarily two or more stories, the roof surfaces are insufficient for all residents to install solar devices, leading to concerns regarding building landscapes. Most SWH consumers are located in the central and southern regions of Taiwan, which receive sufficient insolation.

The installation of traditional solar collectors may affect the appearance of modern buildings, making them difficult to promote. However, Taiwan has recently developed structured and embedded solar collectors that can be installed on slanted roofs, parapets, and canopies. Future developments aim to incorporate solar collectors into the building materials by exploring lighter, more beautiful, and safer building-integrated solar collectors, and examining the interface and regulations for incorporating solar collectors into buildings. In recent years, the BOE, Ministry of Economic Affairs, Taiwan, developed regulations and a reward system for SWHs, and set an annual SWH installation area target of 140,000 m^2 by 2020 [6]. Currently, subsidies to install SWHs have reached NT$2250/$m^2$ in Taiwan [28].

Despite the accelerated internationalization of global SWH industries, more than 99% of the SWH industry in Taiwan supplies the domestic market, and less than 1% of its products are exported [15]. However, the scale of Taiwan's SWH industry is small compared to that of Germany and China. Furthermore, because the domestic market is too small to expand Taiwan's SWH industry, numerous manufacturers must simultaneously develop other products to survive. Therefore, increasing the volume of exports is urgently required to accelerate industry development.

3. Research methods

System dynamics is a methodology developed by Forrester et al. at MIT in 1961. It studies internal information feedback within a system, and utilizes models to improve industry structures and guide policy formation [29]. The development of system dynamics was based on the information-feedback control theory, the decision-making process, an experimental approach to system analysis, and digital computers. By integrating the four theoretical frameworks, system dynamics can be used to address problems with multiple variables, information and causal feedback, dynamics, nonlinearity, and that involve interactions of the entire system. The casual loop and stimulation of the information system shows the structure behind dynamic complexity, explains the dynamic behavior of a system, simulates the interaction effects of policy, and then enables system dynamics to identify

an entry point for policy intervention. This methodology is often used to study the dynamic behavior characteristics of organizations or company systems, and has been widely applied to industry research [30].

System dynamics modeling comprises the following three basic elements: (1) a positive feedback loop, (2) a negative feedback loop, and (3) a delay [31,32]. Forrester [29] believed that the main information of the system structure, delay, and policy significantly influence the results. In system dynamics, model validity is evaluated from a teleological perspective. System structures are used to show the dynamic behaviors of the overall system. A policy intervention point is identified based on the structure to facilitate decisions and enable model users to make decisions that achieve their purposes [33].

Through the many years of development, system dynamics have been employed in various fields of research. Coyle [34] proposed the following structure for applying the system dynamics approach: Stage 1 is problem recognition; Stage 2 is problem understanding and system description; Stage 3 is qualitative analysis; Stage 4 is simulation modelling, including model testing; and Stage 5 is policy testing and design. Stage 1 is to recognize the problem and to find out which people care about it, and why; Stage 2 is the description of the system by means of an influence diagram; Stage 3 is to draw on so-called bright ideas and pet theories. For the stage 4, the influence diagram is usually not even necessary to show every single detail, because the simulation model can be written from it without a separate stage of flow charting. The influence diagram and the simulation model are simply two versions of the same model; one written in arrows and words, the other in equations and computer code. This property is of fundamental importance in system dynamics as it gives rise to some powerful practical consequences. Stage 4 includes the testing and debugging of the model. Stage 5 is where results based on quantitative analysis start to emerge.[34]. Because the problems associated with installing SWHs are complex and dynamic, their thorough examination necessitates a holistic perspective. For this study, we adopted a system dynamics approach to examine these problems and construct a complete system structure for SWH installation for the SWH industry in Taiwan. This model was also used to assist the Taiwanese SWH industry and government in understanding the issues associated with SWH installation and to establish strategies for resolving the industry problems.

4. Model construction and validity

4.1. Model construction

Expert interviews can compensate for insufficient results in a qualitative study. In this study, we conducted in-depth interviews with two sales managers (Suncue Company Ltd. and Sun-King Energy Co., Ltd.) and a senior engineer (Geo-Shine Solar Inc.). The interview topics were the influence that government policies, the market, technology, products, company finance, and management level had on the SWH industry in Taiwan. We reviewed relevant literature, SWH company web sites, and interviewed SWH industry experts in Taiwan to determine the SWH variables and behaviors based on the professional knowledge and ability, practical experience, and opinions of experts. Subsequently, we examined the critical factors of SWH installations in Taiwan based on its causal relationships.

4.1.1. The causal relationships of SWH installation in Taiwan

A study by the Industrial Technology Research Institute (ITRI) [15] suggested that the subsidies provided by the Taiwanese government to the SWH industry also included research and development (R&D) and system costs. Tai et al. [35] found that technology and yield rates positively correlated to cost reduction. Chang et al. [9] believed that the limited number of SWHs installed was because of their high capital costs compared with the costs of conventional heaters. Additionally, the quantity and quality of hot water provided by SWHs is important to consumer faith in SWH. Chang et al. [10] argued that the capital cost of SWHs would be one of major concern and the ownership and architectural type of buildings might limit the available area for SWHs installation. Chang et al. [36] highlighted that solar insolation is one of the major diffusion barriers for households, and systematic efforts must be made to reduce costs through economies of scale.

The causal relationships of SWH installation in Taiwan are shown in Fig. 1. A higher installation inclination can increase the installation areas; however, expanding the installation areas may lead to higher incidence of malfunctions, further weakening installation intentions by forming a negative causal feedback loop (Loop 1).

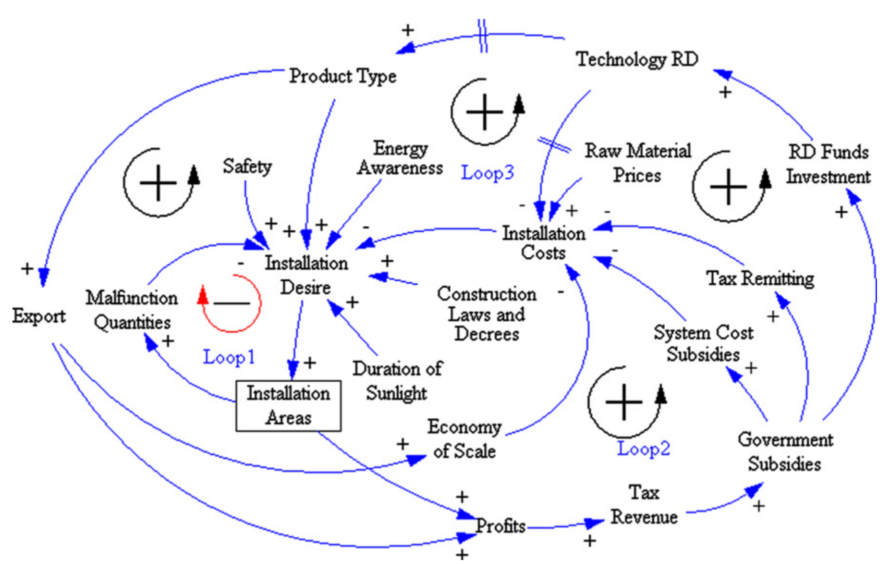


Fig. 1. The causal relationship of SWH installation in Taiwan.

As the government increases subsidies for SWHs, subsidies for system costs can be raised, reducing the SWH installation costs and enhancing installation desire. Greater installation desire may expand installation areas and increase the profits of manufacturers. Increased profits for manufacturers result in more tax revenues for the government, which increases the funds the government has available for subsidizing SWHs; thus, a positive feedback loop is formed (Loop 2). In addition, when the government provides more subsidies for developing SWHs, SWH technology can be improved, resulting in more product types and the greater installation desire. The higher installation desire may increase installation areas and boost the profits of manufacturers. Once the profits of manufacturers improve, the tax revenues of the government will increase, providing the government with more financial resources to sponsor SWH development, forming another positive feedback loop (Loop 3).

4.2. Quantitative model

In this study, we established an operable quantitative model based on the qualitative model described previously. This model included the two primary levels of installation area and government subsidies and 24 formulas. Examples of the relationships between levels and significant variables are provided below.

4.2.1. Installation area dynamic process

The primary level of this dynamic process diagram is the accumulated installation areas. The accumulated installation areas refer to the annual accumulated difference between the installation areas and the demolition areas (Eq. (1) in the Appendix). The installation areas are affected by the installation desire (Eq. (2) in the Appendix). According to the report by the BOE of the MOEA [6], the average life span of SWHs is 15 years. Because of their limited life span, SWHs are dismantled after a certain period (Eq. (3) in the Appendix). Thus, the accumulated installation areas influence the incidence of malfunctions (Eq. (4) in the Appendix) and the installation desire.

4.2.2. The dynamic process of government subsidies

The primary level of this dynamic process diagram is government subsidies, which refers to the accumulated difference between subsidy expenditure and subsidy finance (Eq. (5) in the Appendix). Tax revenue is influenced by profits (Eq. (6) in the Appendix), which influence subsidy finance (Eq. 7 in the Appendix). Meanwhile, profits and the installation areas are related to the volume of exports (Eq. (8) in the Appendix). According to Chang et al. [9], the average duration of sunlight in Taiwan is 1750 h. Installation desire is related to safety, construction laws and regulations, product type, duration of sunlight, malfunction quantities, installation costs, and energy awareness (Eq. (9) in the Appendix); and installation costs are related to system cost subsidies, technology R&D, economy of scale, raw material prices, and tax remitting (Eq. (10) in the Appendix). The technology R&D is related to the R&D funds investment, and the product type is influenced by the technology R&D (Eqs. (11) and (12) in the Appendix).

The two primary levels described previously, that is, the accumulated installation areas and government subsidies, form the dynamic process diagram for SWH installation in Taiwan, as shown in Fig. 2.

4.3. Model validity

Validity is the process of establishing confidence in the completeness and effectiveness of a model [37,38]. Barlas [39] suggested that confidence in a model is based on its framework validity and behavioral validity; however, behavioral validity is meaningful only when sufficient confidence in the model framework exists. Forrester and Senge [38] suggested that the validity of a system dynamics model can be evaluated based on the following three levels: the reliability of the model framework, the degree of similarity between behaviors exhibited by the model and in the real world, and the helpfulness and effects that the model has on policy analysis. Hshieh [30] suggested that system dynamics models should have at least the following characteristics to be considered effective and reliable: (1) the framework relationships and parameters of the variables in the model should correspond to actual systems; (2) the various predicted changes manipulated by a model should correspond to actual operations in real systems; (3) the mechanisms in a model must be identical to those of actual systems; and (4) the outputs of the model must have the same trend characteristics as actual system behaviors. The items used for validity testing of the system model in this study are explained below.

4.3.1. Structure assessment

Sterman [40] and Forrester and Senge [38] stated that whether the relevant knowledge in a model and the actual system are consistent must be assessed. The model in this study was based

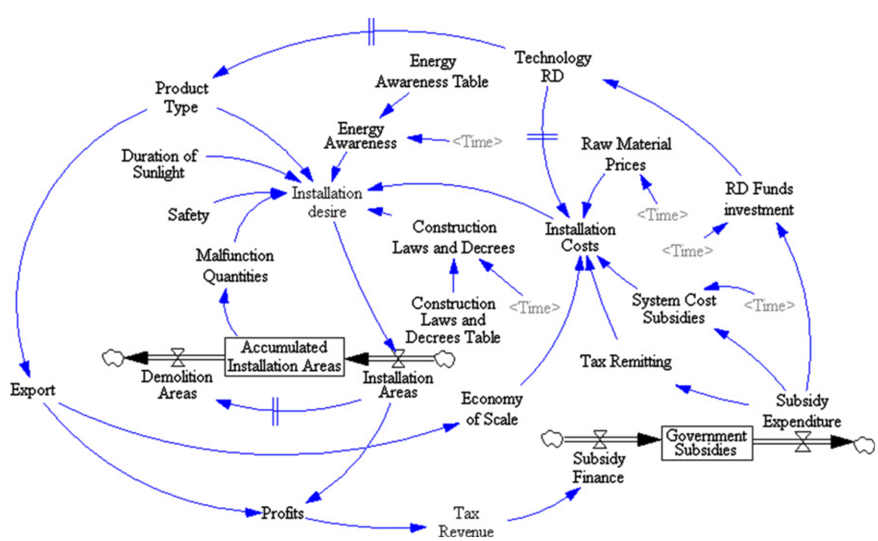


Fig. 2. Dynamic process diagram of SWHs installation in Taiwan.

on relevant literature and reviewed by SWH experts for adjustment; thus, the model corresponds to the actual operations of SWH installation. Additionally, the scope of this study included the critical factors of relevant issues.

4.3.2. Parameter assessment

Sterman [40] recommended that the reasonableness of the values estimated for the parameters be assessed based on relevant data collected. Forrester and Senge [38] suggested that the parameters within a model must be consistent with the relevant descriptions and numerical knowledge of a system. Relevant values collected from other sources (such as journals, government agency web sites regarding SWHs and the web sites of SWH firms) were used to simulate the quantitative model, and the results were constantly compared with historical values to adjust the system when examining the reasonableness of the parameter estimates.

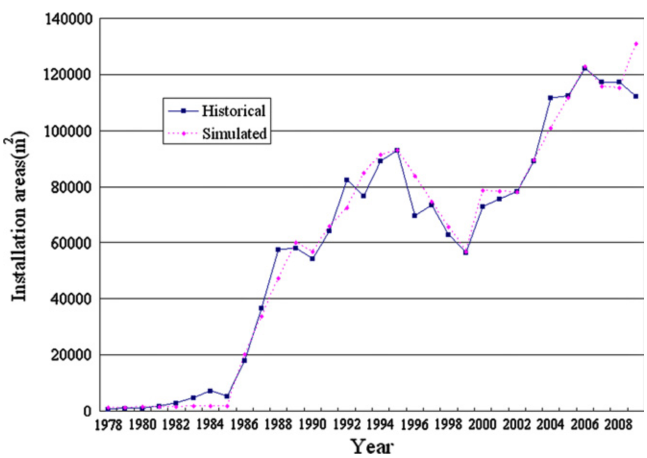


Fig. 3. Comparison of the simulated values and historical values of SWH installation areas in Taiwan.

4.3.3. Behavior reproduction

Behavior reproduction refers to testing to determine whether flaws exist in the parameters and model framework and assessing whether the behaviors of the model are associated with the purposes of the system. Forrester [41] suggested that the goals of models are created to use the historical results to guide current behaviors. Sterman [40] advocated that good models should exhibit behaviors identical to those observed in data. In this study, we compared the historical values of the SWH installation area in Taiwan with the simulated values to examine the model.

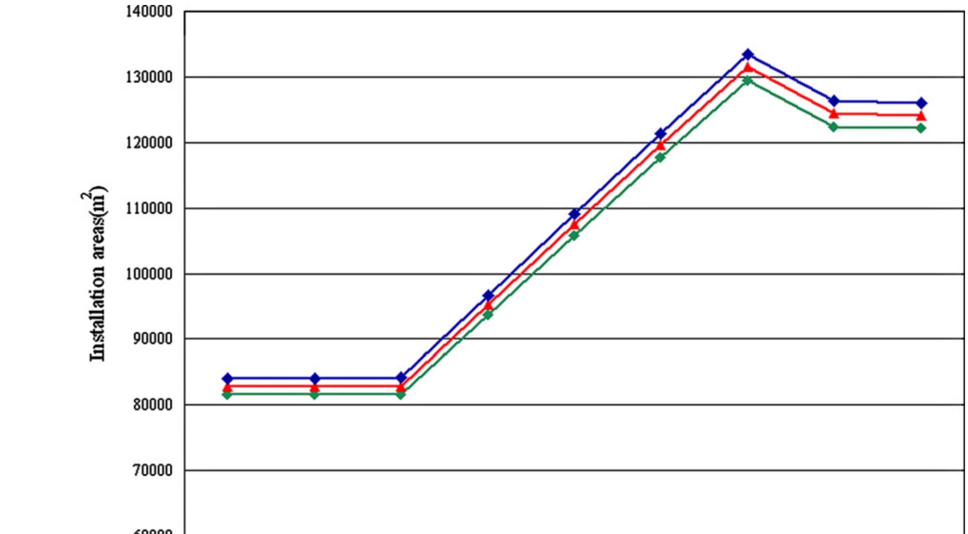
Before 1986, SWH installation in Taiwan was only promoted by the industry, resulting in the slow growth of installation areas. Since the government authorized the first subsidy in 1986, SWH installation costs have decreased and public installation inclinations increased, leading to a rapid growth of installation areas. However, when the government terminated its subsidies in 1993, installation costs increased and public installation inclinations weakened, resulting in a rapid decline in installation areas since 1995. Once the government resumed its subsidies in 2009, SWH installation costs again decreased. However, in the meantime, the public has become increasingly aware of the need to save energy and reduce carbon emissions; thus, installation areas have again increased rapidly. Additionally, the installation areas between 2000 and 2006 exceed the installation areas between 1986 and 1992. Since 2007, increasing raw material prices worldwide (specifically, a more than 20% increase in the price of steel and copper) have resulted in the relatively high cost of SWHs, leading to a more conservative attitude among consumers regarding SWH adoption, and a decrease in installation areas to 1,17,200 m^2. Influenced by the global financial crisis in 2009, the public has become even more reserved regarding SWH installation, causing installation areas to decline further to 1,12,000 m^2. A comparison between the simulated values and historical values of SWH installation areas in Taiwan is shown in Fig. 3 (with the solid line indicating the historical values).

This study compares the values of historical data on SWH installation areas with simulations, and adopts the chi-squared test to assess behavior reproduction. This study sets the confidence

	2000	2001	2002	2003	2004	2005	2006	2007	2008
system cost subsidies=NT$1250	79181	79214	79248	91049	102758	114347	125791	118666	118390
system cost subsidies=NT$1500	82799	82834	82869	95210	107449	119556	131505	124371	124063
system cost subsidies=NT$1750	86417	86454	86490	99370	112139	124763	137215	130072	129730

Year

Fig. 4. The results of sensitivity testing of the system cost subsidies.



	2000	2001	2002	2003	2004	2005	2006	2007	2008
technology RD=70	81546	81580	81615	93769	105824	117751	129524	122424	122125
technology RD=75	82799	82834	82869	95210	107449	119556	131505	124371	124063
technology RD=85	84060	84095	84131	96659	109083	121371	133497	126331	126013

Fig. 5. The results of sensitivity testing of the technology RD.

interval at 5%. Fig. 3 shows a comparison of the simulated and the historical data on SWH installation areas in Taiwan. As the value of the chi-squared test is $\chi^2 = 2.470 \le \chi^2_{0.05}(31) = 44.985$,we may safely accept the model.

4.3.4. Sensitivity analysis

Sterman [40] stated that the sensitivity of parameters to values, the sensitivity of behavioral models, and the sensitivity of policies within models should all be adjusted for testing. The sensitivities between all variables in the model used in this study were tested repeatedly; the system was adjusted based on the results. In the present study, the system cost subsidies and the technology RD are two of the most important variables in the simulation. Figs. 4 and 5 show the results of a sensitivity analysis for these two variables. For the system cost subsidies, three different values, NT\$1250/m^2, NT\$1500/m^2, and NT\$1750/m^2, are used to check the sensitivity.

The system cost subsidies are NT\$1250/m^2, while the installation areas amounted to 1,18,390 m^2 in 2008. When the system cost subsidies increase to NT\$1500/m^2, the 2008 installation areas change to 1,24,063 m^2. So for every NT\$100/m^2 increase in the system cost subsidies, the 2008 installation areas increase by 2269 m^2. When the system cost subsidies increase to NT\$1750/m^2, the 2008 installation areas change to 1,29,730 m^2, suggesting that a NT\$100/m^2 increase in the system cost subsidies increases the installation areas by 2266 m^2 (Fig. 4).

For the technology RD variable, we used three different values, 70%, 75%, and 80%, to check the sensitivity. If the technology RD is 70%, the 2008 installation areas are 1,22,125 m^2. When the proportion of subsidy increases to 75%, the 2008 installation areas change to 1,24,063 m^2; so for every 1% increase in the technology RD, the 2008 installation areas increase by 387 m^2. When the technology RD increases to 80%, the 2008 installation areas change to 1,26,013 m^2, suggesting that a 1% increase in the technology RD increases the installation areas by 390 m^2 (Fig. 5).

5. Simulation results and analysis

In this chapter, we applied the system dynamics model to simulate SWH installation areas in Taiwan. To do so, we analyzed the relationship between SWH installation areas, saving energy, and carbon reduction, comparing different policy measures' benefits with regard to saving oil and reducing CO_2 emissions from 2012 to 2020. Simulations were conducted for different scenarios using policy measures to subsidize system costs and subsidize R&D costs, change raw material prices, and change tax remittances.

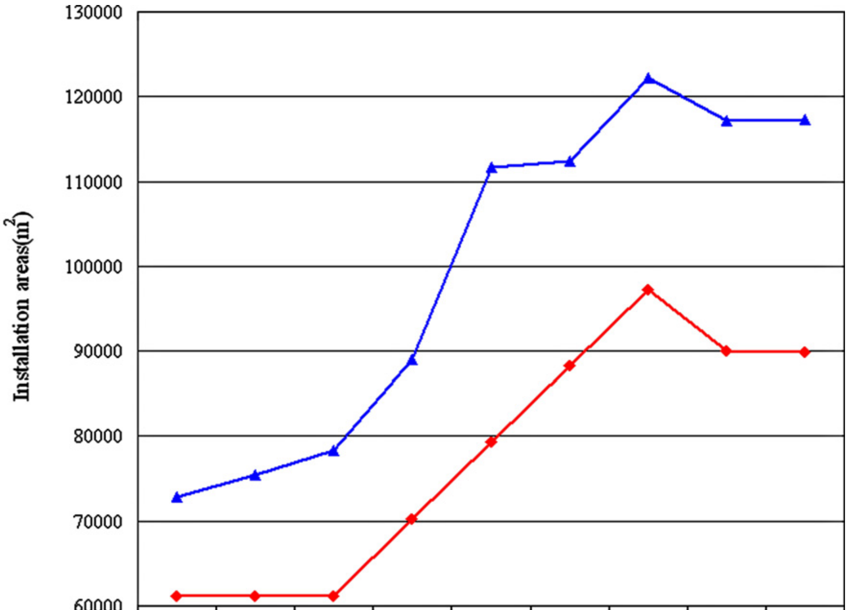
5.1. Evaluation of SWH installation areas in Taiwan

The Taiwanese government provided subsidies for SWH installation of NT\$1500/m^2 from 2000 to 2008. Fig. 6 shows that without a promotion policy between 2000 and 2008, the SWH installation areas would have been 89,924 m^2 in 2008. The government invested NT\$175.95 million, increasing 2008 SWH installation areas by 27,376 m^2, saving approximately 1.86 million liters of oil and reducing CO_2 emissions by approximately 5.2 million kg annually.

5.2. Simulation and analysis of government policies for subsidizing system costs

We simulated the following three scenarios of government policies to subsidize system costs: the government in Taiwan terminating subsidies for SWH installation; the government reducing the subsidies to NT\$1500/m^2 from 2012 because of budget limitations; and the government increasing subsidies to NT\$3000/m^2 from 2012 to reduce carbon emissions more drastically. The simulation results are shown in Fig. 7.

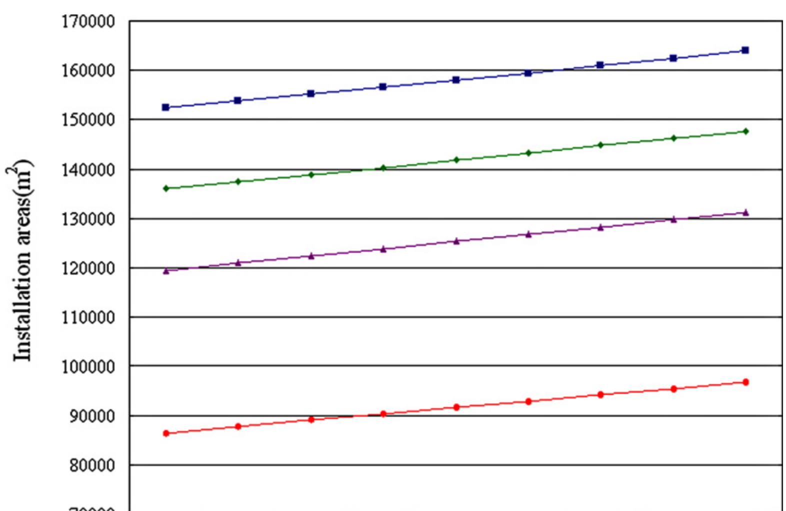
For the scenario in which the government no longer subsidizes SWHs after 2012, the simulation results showed that SWH installation areas would be 96,847 m^2 in 2020. This would bring an increase of approximately 3.45 million l of oil and 9.65 million kgs



	2000	2001	2002	2003	2004	2005	2006	2007	2008
Without promotion policies	61090	61116	61142	70247	79299	88281	97178	90065	89924
With promotion policies	72800	75500	78300	89000	111600	112400	122200	117200	117300

Year

Fig. 6. Comparison of SWH installation areas in Taiwan with and without subsidies.



	2012	2013	2014	2015	2016	2017	2018	2019	2020
To increase subsidies to NT$3,000/m2	152369	153746	155142	156558	157991	159440	160905	162383	163874
To decrease subsidies to NT$1,500/m2	119418	120872	122327	123784	125240	126697	128154	129610	131066
To terminate subsidies	86466	87791	89108	90416	91717	93010	94296	95575	96847
Now(Subsidies are NT$2,250/m2)	135894	137335	138785	140244	141711	143185	144666	146152	147643

Year

Fig. 7. Simulation of the influence that government policies to subsidize system costs would have on SWH installation areas.

of CO_2 emissions annually, and would not achieve the planned promotion target by 2020 (1,40,000 m^2 of installation areas annually). Showing that for every NT$500/$m^2$ decrease in the system cost subsidies, the 2020 SWH installation areas decrease by 11,288 m^2. If the government reduces subsidies to NT$1500/$m^2$ after 2012, the SWH installation areas will only be 131,066 m^2 in 2020, which would mean an increase of approximately 1.13 million l of oil and 3.15 million kgs of CO_2 emissions annually, and would not achieve the planned promotion target of 140,000 m^2 by 2020. Therefore, for every NT$500/$m^2$ decrease in the system cost subsidies, the 2020 SWH installation areas decrease by 11,051 m^2. Finally, if the government increases subsidies to NT$3000/$m^2$ after 2012, the SWH installation areas will exceed 160,000 m^2 in 2020, which would save approximately 1.1 million l of oil and reduce CO_2 emissions by

approximately 3.08 million kg annually. Meaning that for every NT\$500/m^2 increase in the system cost subsidies, the 2020 SWH installation areas increase by 10,820 m^2.

5.3. Simulation and analysis of government policies to subsidize R&D costs

Regarding government policies for subsidizing R&D costs we simulated three scenarios, in which the government in Taiwan increases subsidies for R&D funds by 10%, 20%, and 30%, in order to enhance energy saving and carbon reduction benefits (assuming subsidies for SWH installation remain at NT\$2250/m^2).

If the government increases subsidies for R&D funds by 10% from 2012, SWH installation areas will be 1,48,347 m^2 in 2020, which would save approximately 47.87 thousand liters of oil and reduce CO_2 emissions by approximately 133.76 thousand kilograms annually. So for every 1% increase in the R&D costs subsidies, the 2020 SWH installation areas increase by 70.4 m^2. If the government increases subsidies for R&D funds by 20% from 2012, 2020 SWH installation areas will be 1,49,052 m^2, saving approximately 95.81 thousand liters of oil and reducing CO_2 emissions by approximately 267.71 thousand kilograms annually. Finally, if the government increases subsidies for R&D funds by 30% from 2012, 2020 SWH installation areas will be 149,758 m^2, which would save approximately 143.82 thousand liters of oil and reduce CO_2 emissions by approximately 401.85 thousand kgs annually. This is primarily because SWHs are already a mature product; thus, technological developments cannot significantly reduce SWH costs, instead they are focused on SWH applications, as shown in Fig. 8.

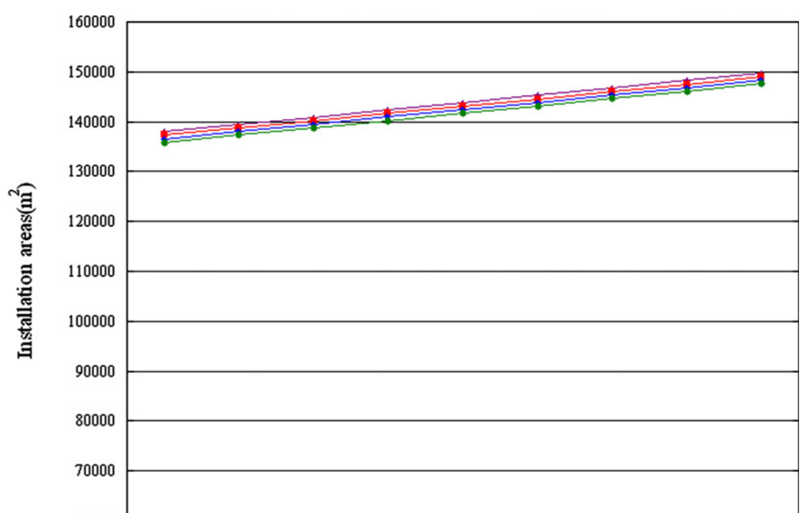
5.4. Simulation and analysis of changes in raw material prices

Regarding changes to raw material prices, we simulated three scenarios, in which the prices of steel and copper change by −20%, −10%, +10%, and +20% (assuming the subsidies for SWH installation remain at NT\$2250/m^2).

If steel and copper prices decrease by 10% from 2012, SWH installation areas will be almost 1,50,000 m^2 in 2020, bringing a saving of approximately 214.13 thousand liters of oil and a reduction in CO_2 emissions of approximately 598.31 thousand kilograms annually, indicating that for every 1% increase in raw material prices, the 2020 SWH installation areas increase by 316.1 m^2. If steel and copper prices decrease by 20% from 2012, 2020 SWH installation areas will be 153,927 m^2, saving approximately 427.31 thousand liters of oil and reducing CO_2 emissions by approximately 1.2 million kg annually. If steel and copper prices increase by 10% from 2012, 2020 SWH installation areas will be 144,482 m^2, bringing an increase of approximately 214.95 thousand liters of oil and 600.59 thousand kilograms of CO_2 emissions annually. If steel and copper prices increase by 20% from 2012, by 2020, SWH installation areas will be 1,41,308 m^2, increasing oil by approximately 430.78 thousand liters and CO_2 emissions by approximately 1.2 million kgs annually. Finally, if steel and copper prices increase by more than 20% from 2012, the government should increase subsidies promptly to achieve the planned promotion target by 2020 (1,40,000 m^2 of installation areas annually), as shown in Fig. 9.

5.5. Simulation and analysis of changes in tax remittance

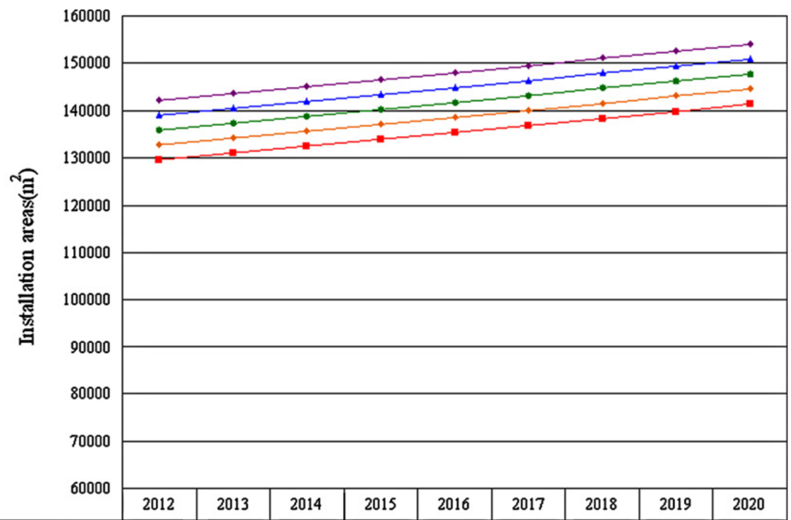
Regarding changes in tax remittance, we simulated three scenarios, in which tax remittance changes by +10%, +25%, and +50%. If tax remittance increases by 10% from 2012, SWH installation areas will be 1,47,746 m^2 in 2020, which would save approximately 7 thousand liters of oil and reduce CO_2 emissions by approximately 19.57 thousand kilograms annually. Therefore, for every 10% increase in tax remittance, the 2020 SWH installation areas increase by 103 m^2. If tax remittance increases by 20% from 2012, 2020 SWH installation areas will be 147,899 m^2, saving approximately 17.4 thousand liters of oil and reducing CO_2 emissions by approximately 48.64 thousand kilograms annually. If tax remittance increases by 50% from 2012, 2020 SWH installation areas will be 1,48,155 m^2, saving approximately 34.82 thousand liters of oil and reducing CO_2 emissions by approximately 97.28



	2012	2013	2014	2015	2016	2017	2018	2019	2020
The subsidies for R&D funds +30%	137996	139435	140885	142344	143812	145288	146772	148262	149758
The subsidies for R&D funds +20%	137294	138733	140183	141643	143111	144586	146069	147557	149052
The subsidies for R&D funds +10%	136593	138033	139484	140943	142410	143885	145366	146854	148347
Current situation	135894	137335	138785	140244	141711	143185	144666	146152	147643

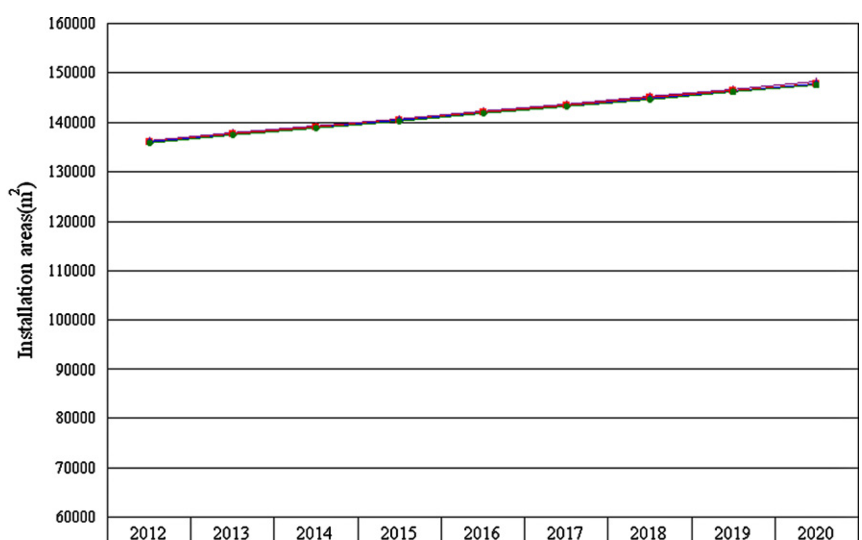
Year

Fig. 8. Simulation of the impact of government policies to subsidize R&D funds on SWH installation areas.



	2012	2013	2014	2015	2016	2017	2018	2019	2020
The prices of steel and copper -20%	142231	143654	145089	146537	147996	149466	150945	152432	153927
The prices of steel and copper -10%	139062	140495	141939	143393	144857	146330	147810	149298	150792
The prices of steel and copper +10%	132725	134172	135628	137090	138558	140032	141511	142995	144482
The prices of steel and copper +20%	129556	131008	132466	133930	135398	136871	138347	139826	141308
Current Situation	135894	137335	138785	140244	141711	143185	144666	146152	147643

Fig. 9. Simulation of the impact that changes in raw material prices would have on SWH installation areas.



	2012	2013	2014	2015	2016	2017	2018	2019	2020
The tax remitting +50%	136378	137823	139277	140739	142209	143687	145171	146660	148155
The tax remitting +25%	136136	137579	139031	140492	141960	143436	144918	146406	147899
The tax remitting +10%	135991	137432	138884	140343	141811	143286	144767	146254	147746
Current situation	135894	137335	138785	140244	141711	143185	144666	146152	147643

Fig. 10. Simulation of the influence of changes in tax remittance on SWH installation areas.

thousand kilograms annually. This is primarily because the tax remittance only amounts to a small proportion of SWH installation costs, as shown in Fig. 10.

6. Conclusions

SWH installation in Taiwan is a complex and dynamic process that is influenced by various factors, such as government subsidies and installation costs. This study adopted the system dynamics method to explore the dynamic model of SWH installation development in Taiwan, analyzed significant causal loops between SWH installation and government policies, and explained SWH installation behavior in Taiwan. The development model of SWH installation in Taiwan primarily comprises interactions between the levels, such as government subsidies and the installation area. Therefore, this study used the proposed model to simulate future trends and the influence that government subsidies have on SWH installation in Taiwan.

The results of the trend simulation show that, assuming the government continues to subsidize SWH installation areas by NT$2250/m^2, SWH installation areas will be approximately

1,46,000 m^2 in 2020. In other words, the potential SWH installation area in 2020 could save approximately 9.928 million l of oil and reduce approximately 27.74 million kg of CO_2 emissions annually. If the life of SWHs is 15 years, the installed SWHs could save approximately 148.92 million l of oil and 416.1 million kg of CO_2 emissions overall by 2020. The result of energy saving and carbon reduction can contribute to Taiwan with the lack of energy and needs for economic development.

Although the simulation results regarding government policies for subsidizing R&D costs show that the SWH installation area cannot be expanded significantly, the Taiwanese government should continually subsidize R&D costs to significantly improve the efficiency of SWH and facilitate the discovery of new resources in the future. This will reduce the costs of SWH operation and, thus, increase the use of SWHs outside the home or in more stories.

The primary barrier to SWH installation is that the installation costs of SWHs exceed those of gas water heaters and electrical water heaters. The simulation results show that if the government increases SWH subsidies or the SWH raw material prices decline, the SWH installation areas will increase significantly. Therefore, the government can use other policies to stimulate a reduction in SWH installation costs, as well as provide subsidies to further reduce SWH installation costs. For example, the Taiwanese government can assist the SWH industry in expanding economies of scale by increasing the volume of exports and creating opportunities for rapid growth through explicit technologies, investments, and marketing platforms to reduce SWH installation costs. The results will increase public willingness and inclination to installing SWHs.

Appendix. Dynamic equation

$$\text{accumulated installation areas} = \text{INTEG (installation areas} - \text{demolition areas, 0)} \quad (1)$$

$$\text{installation areas} = 52{,}0000 \times \text{ installation desire} \quad (2)$$

$$\text{demolition areas} = \text{DELAY1 (installation areas, 15)} \quad (3)$$

$$\text{malfunction quantities} = 0.05 \times \text{accumulated installation areas} \quad (4)$$

$$\text{government subsidies} = \text{INTEG (subsidy finance} - \text{subsidy expenditure, 0)} \quad (5)$$

$$\text{tax revenue} = 0.15 \times \text{profits} \quad (6)$$

$$\text{subsidy finance} = 0.2 \times \text{tax revenue} \quad (7)$$

$$\text{profits} = 1/2 \times \text{export} + 3500 \times \text{installation areas} \quad (8)$$

$$\begin{aligned}\text{installation desire} &= 9.5 \times (\text{safety} + \text{construction laws and decrees}/10 \\ &\quad + \text{producttype}/100 + \text{durationofsunlight}/1750 \\ &\quad - \text{malfunctionquanties}/500000) \\ &\quad \times (1 - \text{installationcosts}/60{,}000) \times \text{energy awareness}\end{aligned} \quad (9)$$

$$\begin{aligned}\text{installation costs} &= (60{,}000 - \text{system cost subsidies} - \text{tax remitting}) \\ &\quad \times (1 - \text{technologyR\&D}/50 - \text{economy of scale}/10) \\ &\quad \times \text{raw material prices}\end{aligned} \quad (10)$$

$$\text{technology R\&D} = 0.6 + \text{R\&Dfunds investment}/2\text{e}+008 \quad (11)$$

$$\text{product type} = 10 \times \text{technology R\&D} \quad (12)$$

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